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MICROPROCESSORS AS AIRCRAFT FATIGUE MONITORS

BY

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A feasibility study has been completed on the use of a microprocessor as an aircraft in-flight fatigue monitoring device. Two prototypes have been assembled and successfully laboratory tested. The study has shown great promise in dollar savings by providing local strain data from which aircraft life predictions can be made more accurately.

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ABSTRACT

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I. INTRODUCTION

When loads are repeatedly applied to a metal specimen , failure can be produced at load levels which would not cause failure with only a single application. In aircraft, flight loads on the wing produced by maneuvers and wind gusts cause the wings to be cyclicly loaded through a random history, making fatigue a matter of serious concern in aircraft design. In actuality, structural fatigue is the factor that determines the life of the airplane and is often the driver in establishing dimensions of structural components.

Each airplane of a given type flies such a completely different profile, although designed to perform the same mission, that the loading history is quite unique. As a consequence, there is a need to monitor every airplane and record the number, magnitude and sequence of the repeated loads. This requirement can be nicely fulfilled through application of an onboard microprocessor data acquisition system.

The system which was developed is comprised of two major subsystems: the WRITE subsystem and the READ subsystem. The WRITE subsystem is tasked with the airborne collection of data. It makes use of a microprocessor, various components for signal processing, a magnetic tape recorder, and a strain gage network to monitor strain-generated signals, identify significant events, and record the collected data. The READ subsystem is tasked with the retrieval of the data from the WRITE subsystem recorder. A desk-top calculator and cassette tape reader accomplish this task, which includes the read-back of the magnetic tape, the pre-processing of data, and the operation of a data file retrieval system.

A prototype system has been built and tested by controlling input signals and comparing them with the output which was retrieved. Consistent data correlation indicated that the system is feasible. The employment of the system, as envisioned, is discussed herein, as well as the options which already exist with the rapid advance of microcomputer technology.

II. THE WRITE SYSTEM

The WRITE subsystem of the fatigue life data acquisition system is dedicated to the sensing of significant strain events which have been experienced by the aircraft and the recording of those events. It includes various hardware components used to monitor, digitize, process and record signals, which are generated by strain gages, located at up to eight critical points of interest. The software package of the microprocessor controls the hardware components and monitors their functions. Screening, formatting, storing and recording of data are also functions performed by the software package.

The MPS-803 microprocessor is a microcomputer capable of handling data and performing arithmetic and logical operations. The microprocessor is physically comprised of three 4-1/2 inches by 6-1/2 inches printed circuit cards: the CPU card, the ROM/RAM card and the I/O card.

Of greatest significance on the CPU card are the crystal clock, which provides the timing for the microprocessor, and 8008 CPU (central processing unit), which executes instructions located in the memory of the microprocessor. The executable instructions are generally arithmetic and logic operations, addressing of input/output ports and accessing of memory locations.

The ROM/RAM card contains four PROMs (programmable memory) and sixteen RAM chips (random access memory). Each PROM contains one page of memory storage for 256 bytes of information. Each byte is an instruction word represented by an 8-digit binary number (8 bits). The four PROMs, collectively referred to as ROM, provide a total of 1024 memory locations. The PROMs are the only non-volatile, unalterable storage in the microprocessor and are therefore the only suitable storage for the program instructions. This is virtually the only restriction on the size of the control program. The current program allows for at least one-half page expansion.

The sixteen RAM chips on the ROM/RAM card represent 2K ($K=2^{10}$) memory locations. The RAM chips, collectively referred to as RAM, provide storage which are alterable by the CPU during the execution of the program. Consequently, the first page (256 bytes) of RAM is used for the storage of program variables, and the remaining seven pages (1792 bytes) of RAM are available for data storage. Unlike ROM, RAM storage is volatile and cannot be retrieved after an interruption of power.

The I/O card provides 28 TTL (transistor-transistor logic) compatible input/output lines. The circuits are selectable in groups of four to various combinations of input and output ports. The current configuration assigns the first eight lines to input port zero, the second eight lines to input port one, the third eight lines to output port two, and the remaining four lines to output port three.

A/D Signal Processing Module

The analog signals from the strain gages must be digitized in order to be analyzed and stored by the microprocessor. The module provides for multiplexer, which is driven by a binary up-down counter. The counter provides the channel number, and the multiplexer selects the channel. A sample and hold component is used to stabilize the voltage of the input analog signal, which allows signal digitization by the analog-to-digital converter (ADC). The resultant output of the ADC is an 8-bit binary representation of the analog input. The binary up-down counter and multiplexer are necessary only in order to allow monitoring of multiple channels. A schematic of the system is shown in Figure 1.

Recorder

The recorder employed is the Memodyne Model 171 magnetic tape recorder. The Model 171 is a write-only (record-only), parallel data machine. The recorder inputs each data byte in 8-bit parallel form and formats the word

into a serial format suitable for recording on the tape. The Model 171 achieves a recording density of 40 bytes per inch of magnetic tape (320 bits/inch). The magnetic tape used is a digital quality, standard size cassette with a length of 300 feet. This allows the recording of up to 144,000 bytes (1,152,000 bits) on a single cassette. The nominal rated speed of recording is 100 bytes per second (800 bits/second); however, the developmental system was consistently operated at 110-120 bytes per second without difficulty.

Peripheral Inputs

The header switch is a two-position toggle switch used to advance the tape beyond its leader and to write identifying information at the beginning of the tape. Activating the switch advances the tape, ensuring that the tape leader does not interfere with the recording process. This also provides a blank portion at the beginning of the magnetic tape and further reduces the uncertainty involved in locating the recorded data when attempting to read it back. Deactivation of the switch causes the header information to be written on the tape, and the system enters the data collection mode.

The thumbwheel switches are a series of six, 10-position switches. The six switches allow the 6-digit aircraft bureau number to be indicated. These switches then become a source for identifying information to be included in the header.

The weight-on-wheels switch is a two-position switch, which indicates that the aircraft is on deck or airborne by sensing the extension of the landing gear oleo. The switch is activated while the oleo is compressed, which indicates to the system that a removal of power may be imminent. The system responds by recording the data which are located in the volatile RAM to prevent its loss upon removal of power to the system.

Software Package

The WRITE system software package is a single program of instructions for the 8008 CPU. The total number of instructions is less than 1000 words, which are stored in the four PROMs of the MPS-803 microprocessor. The program was written in PL/M, a higher-level programming language for microprocessors, and coverted to 8008 instructions by the PLM8 compiler, a resident program on the Naval Postgraduate School IBM-360 computer. The INTELLEC 8 microcomputer was used as the means for programming the PROMs and was also used as a developmental tool to simulate the MPS-803 microprocessor, since both utilize the 8008 CPU and 8008 instruction set.

The first step of the poogram starts an initialization process which assigns the desired initial values for various variables used later in the program. Because the program operates by comparing successive signal inputs, the initialization provides for the first sampling of each channel to be stored in order to establish a basis of comparison for subsequent samplings. After initialization the system enters a repetitive process, which will continue until the removal of power.

The header switch is examined to determine its status. If it has been activated, the recorder motor drive is energized to advance the tape for approximately nine seconds, which is sufficient to ensure that the head of the recorder is positioned beyond the tape leader. Upon deactivation of the header switch, the thumbwheel switches are examined and the header information derived is recorded on the tape.

The weight-on-wheels switch is then examined. An activated switch indicating the aircraft is on deck causes a programmatic timer to be started which provides for the recording of data at intervals of 30-35 seconds in order to prevent loss of data in RAM upon removal of power. An airborne indication results in the normal continuation of the program, which provides

for the recording of data only when the RAM capacity has been exceeded.

After the switches have been examined, the signal input channels are multiplexed. Each channel's signal is compared with its previous sample. If, as a result of this comparison, it is determined that no changes have occurred; then the program continues by re-examining the header and weight-on-wheels switches and re-sampling the signal input channels repetitively until a change is identified.

The change of a signal is the first indication that an event may be strain significant. The sign of the slope of the change is determined and compared with the sign of the slope of the previous change. Any change in sign will identify a peak or a valley in the analog signal and is further indication that a strain-significant event may have occurred. Furthermore to be significant, the value of the strain reading must be above a predetermined positive threshold or below a predetermined negative threshold. To aid in the analysis of the data, the first peak or valley following a strain significant event is considered to be significant regardless of the threshold criterion. Consequently the threshold criterion functions to replace multiple occurrences within the threshold by a single event.

Once a signal has been determined to be a strain-significant event, it is identified by channel number and stored in RAM. If an event fills the last storage location in RAM, the recording procedure is initiated. The seven pages of RAM containing the data words are transferred byte-by-byte to the recorder and written on the magnetic tape. The transfer takes slightly more than fifteen seconds, during which time the signal input channels are not monitored. Upon completion of the transfer, the seven pages of RAM are free to be refilled. A schematic of the entire process is shown in Figure 2.

III. THE READ SYSTEM

The READ subsystem of the fatigue life data acquisition system is dedicated to the reading (or playback) of the magnetic tape created by the WRITE subsystem. Its functions include reading, re-formatting, sorting, filing and file retrieval of the data on the magnetic tape. These tasks are accomplished with a minimum of hardware complexity and lengthy, but relatively uncomplicated, software.

The recorder employed is the Memodyne Model 172 magnetic tape recorder. The Model 172 is a read-only (playback-only), parallel data machine. The recorder reads the data in eight bit segments from the tape and assembles the word into an 8-bit parallel format. The nominal rated speed of reading is 80 bytes per second (640 bits/second); however, the developmental system was operated at approximately 25 bytes per second.

The Hewlett-Packard Model 9830 Calculator is the main computing component of the READ system. The HP 9830 calculator is small enough to be used on a desk top and may be configured to accept electrical power from various sources including 110 VAC or 220 VAC. The HP 9830 is programmable from its typewriter-like console or from magnetic tape files. The magnetic tape file system is a built-in read/write cassette recorder, which allows storage of program files and data files on a digital quality, standard size cassette. The proprietary nature of the file operating system prevents the use of the built-in recorder for reading of cassette files that have been created by machines other than HP 9800 series.

The HP 9830 calculator may be equipped with various peripheral devices. These devices include, among others, printers, x-y plotters, card readers, teletypewriters, paper tape readers and external cassette tape recorders. The use of most peripheral devices requires installation of the Extended Input/Output Read-Only Memory, which is a user- accessible plug-in device.

Utilization of the software package on the HP 9830 requires 4K of augmented memory and the Matrix Operations Read-Only Memory.

The Hewlett-Packard TTL I/O Parallel Interface is also required to allow the transfer of data between the HP 9830 and a Peripheral device in an 8-bit parallel format. The parallel interface is a plug-in module which physically connects the I/O lines of the HP 9830 and, in this application, the I/O lines of the Memodyne recorder.

IV. TEST RESULTS

The testing of the fatigue monitoring data acquisition system was conducted in a laboratory environment at the Naval Postgraduate School. Channel 1 of the signal input channels was connected to ground, and the remaining 7 channels were connected to known signals. Channels 2, 3, and 4 received a sinusoidal signal with amplitude of ± 3.7 volts. Channels 5, 6, 7, and 8 received an oscillating signal of variable amplitude between ± 5 volts. The rate of occurrence of significant events was controlled by selecting the frequency of oscillation. The measurement of the elapsed time between input of the data and transfer to the magnetic tape was consistent with the known occurence rate of the peaks and valleys of the input signal.

The reading of the data tape further confirmed the operation of the fatigue monitoring data acquisition system. Channel 1 was determined to be void of strain-significant occurrences. Channels 2, 3, and 4 exhibited an alternating signal of +12 and -12 which corresponds to approximately ± 3.75 volts. Channels 5, 6, 7, and 8 exhibited data which was consistent with the general oscillatory signal on the corresponding signal input lines.

The analog input signal on channel 2 was 3.7 volts, and the fatigue monitoring data acquisition system processed the signal resulting in the value 12. THE ADC outputs digital values on a scale 0000$0000B to 1111$1111B corresponding to input voltages in the range of ± 5 volts, with 1000$0000B corresponding to zero volts. Since 3.7 volts is .74 of 5 volts, the ADC should output the binary value corresponding to .74 of the digital scale above 1000$0000B. That value is 1101$1111B. The rounding off by the WRITE system software results in the value 1110$0000B. The READ/STORE program interprets this value as its decimal equivalent 28. This value is re-scaled to place zero in the center, corresponding to zero strain, by subtracting 16, which results in the final value of 12. The value 12 is representative of

.75 (12/16) of 5 volts, which is 3.75 volts. The values 11 and 13 would represent 3.44 volts and 4.06 volts respectively; so 12 actually represents $3.75 \pm .15$ volts, which is consistent with the analog value of 3.7 volts. (Refer to Figures 3 and 4).

The forerunner of this unit was also successfully flight tested for approximately 30 hours in a Cessna 310, accepting data from a variety of transducers from strain gages to accelerometers. Currently, the Naval Air Development Center is preparing a Request for Proposals for four units for environmental tests and flight tests on high performance aircraft.

V. DISCUSSION

Since the development of the prototype, Intel has produced the 8748 chip which puts the entire microcomputer on a single chip with 8-bit CPU and 1K of erasable program memory. Equipped with 27 I/O lines, it is ideal for this application. Texas Instruments' bubble memory is the ideal device to replace the tape recorder since tape recorders do not function reliably in many aircraft environments, and the nonvolatile nature of the bubble memory coupled with a large capacity will team with the 8748 to make a two or three chip system for aircraft fatigue monitoring.

The microcomputer is an ideal device for aircraft applications. There are many highly complex operations on airplanes to be performed, monitored or controlled, and size and weight are always at a premium. There is not doubt there will be a large demand for them in a large variety of applications.

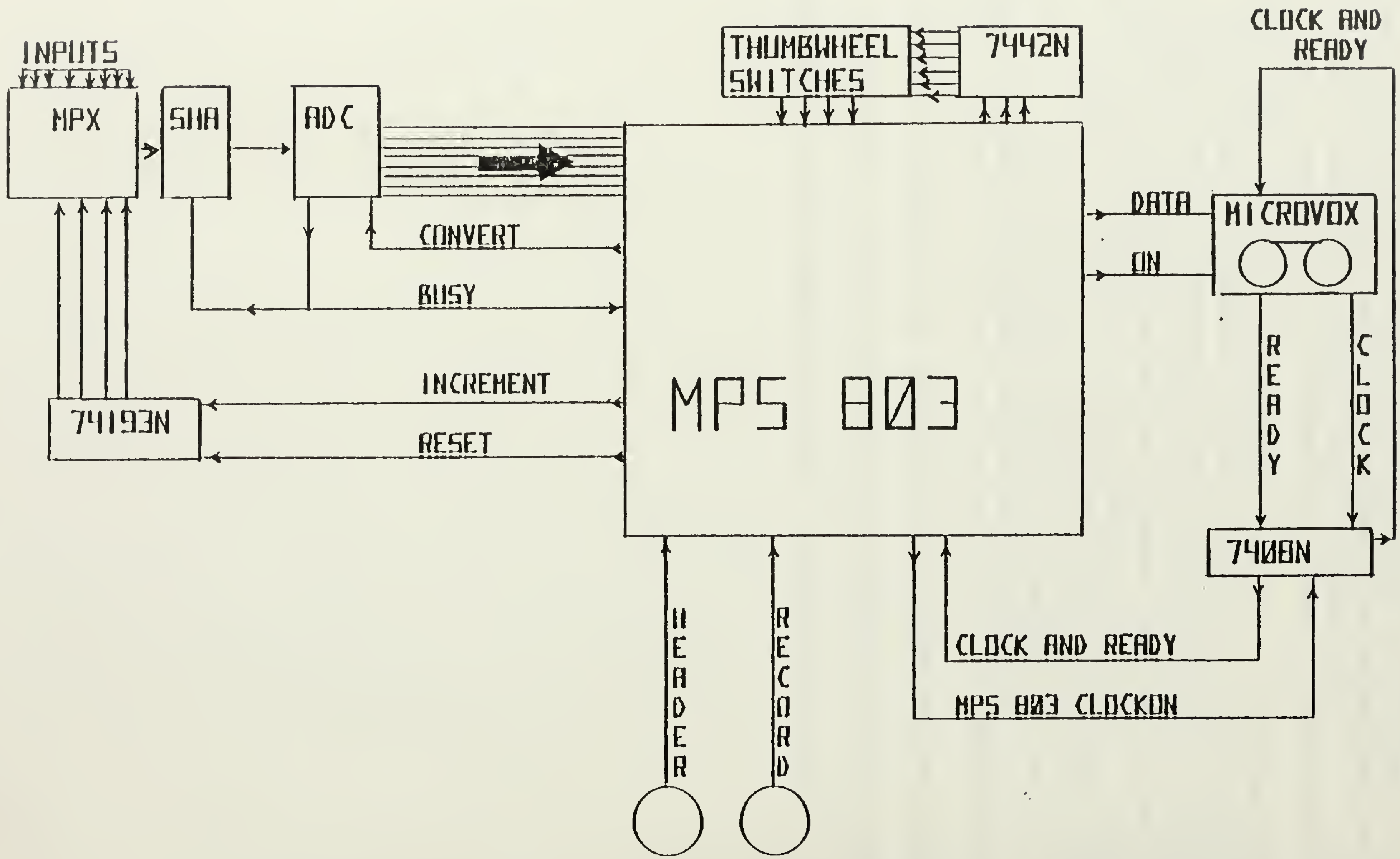

FIGURE 1. MIDAS FLD SYSTEM BLOCK DIAGRAM

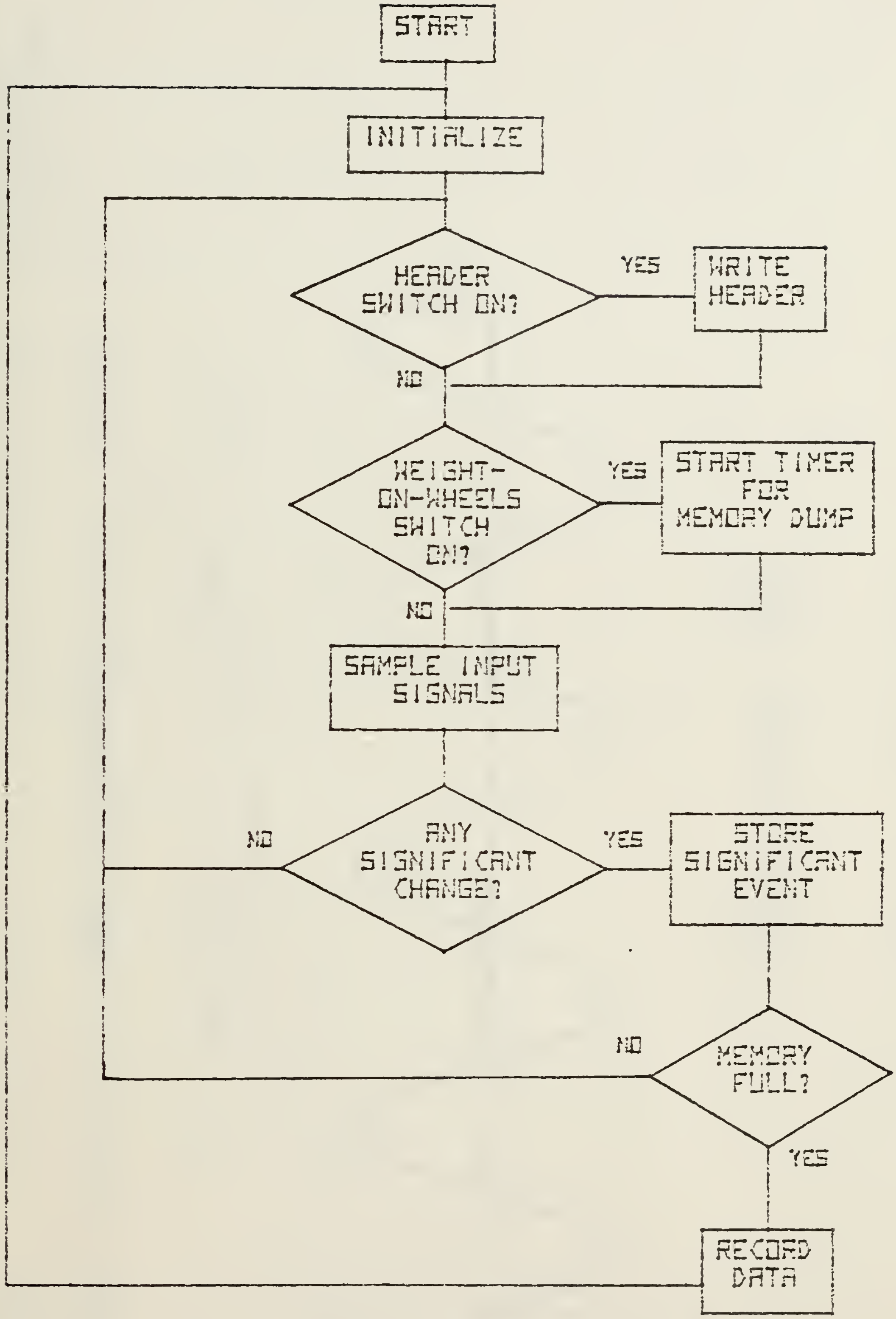

Figure 2 - Flowchart: WRITE Program

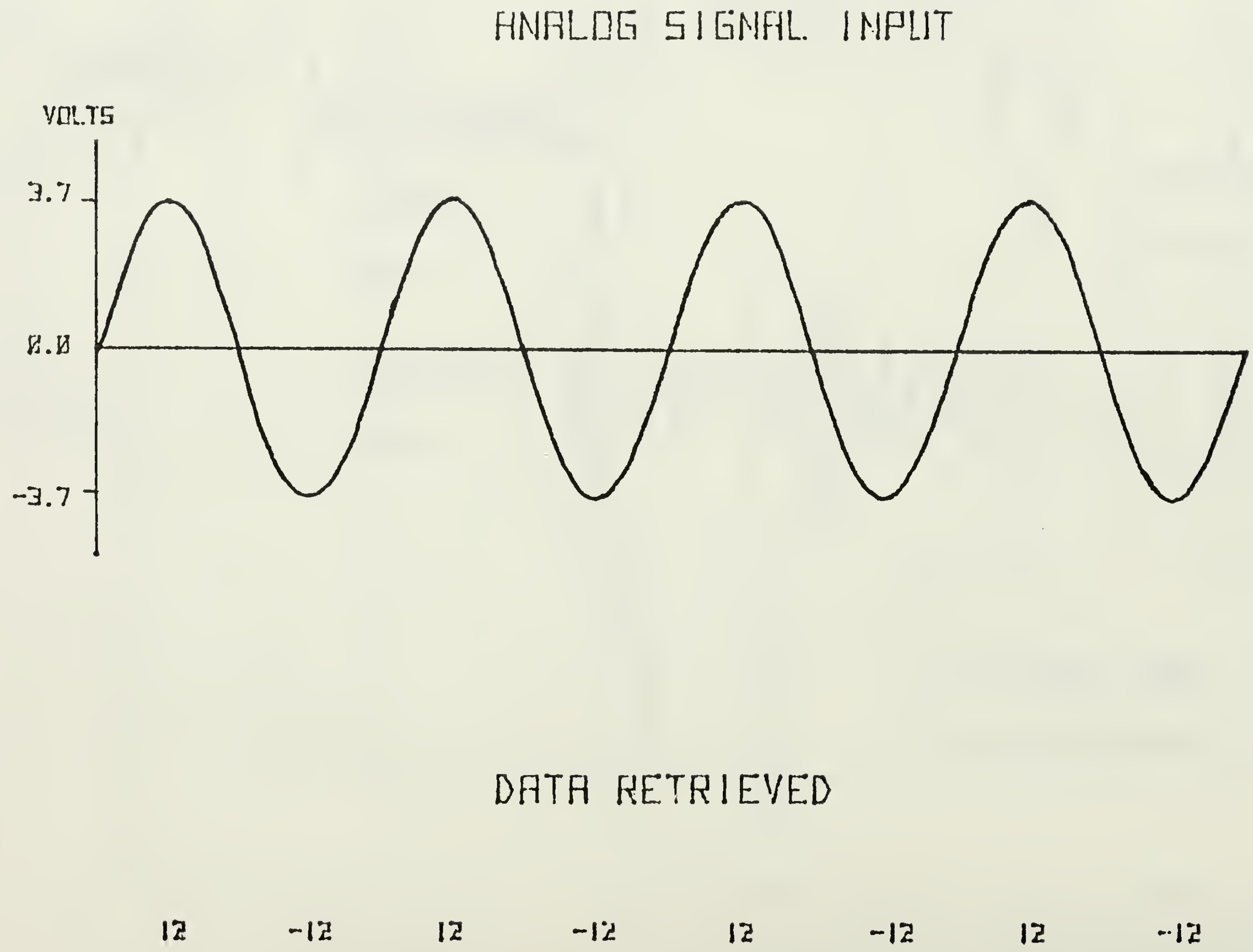

Figure 3 - Input/Output Comparison (Channel 2)

ANALOG SCALE (VOLTS)	DIGITAL SCALE (DECIMAL)	DIGITAL SCALE (BINARY)		5-BIT ROUNDED SCALE (BINARY)	5-BIT ROUNDED SCALE (DECIMAL)	READ SYSTEM SHIFTED SCALE
5	256	10000 0000		100000	32	16
		(1111 1111)	UPPER BOUND	(11111)	(31)	(15)
3.7	223	1101 1111		11100	28	12
0	128	1000 0000		10000	16	0
-5	0	0000 0000		00000	0	-16

Figure 4 - Signal Scales

VI. REFERENCES

More detailed accounts of the hardware, software, design, performance and tests are given in the following theses:

1. David M. Vidrine, "A Sequential Strain Monitor and Records for Use in Aircraft Fatigue Life Prediction", Master's Thesis, Naval Postgraduate School, June 1975.
2. J. W. Sturges, "Microprogrammable Data Acquisition System", Engineer's Thesis, Naval Postgraduate School, June 1975.
3. W. C. Stanfield, "Microprogrammable Integrated Data Acquisition System: Fatigue Life Data Application", Master's Thesis, Naval Postgraduate School, March 1976.
4. C. Lynn Butler, "Software Design for a Fatigue Monitoring Data Acquisition System", Master Thesis, Naval Postgraduate School, September 1976.

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